



L-H transition and pedestal MHD at JET: M-mode, HFO, ELMs

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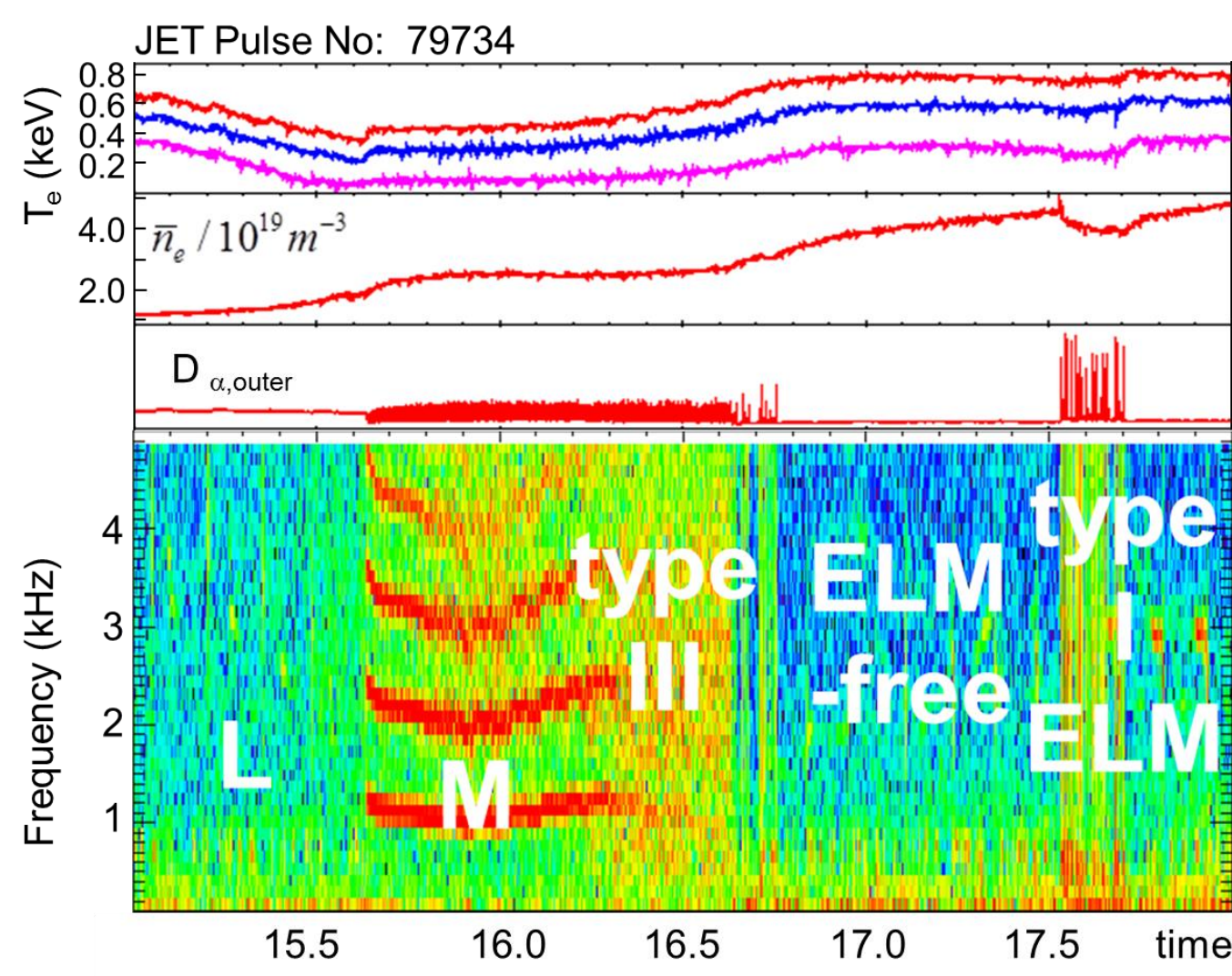
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* See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia

DESCRIPTION OF M-MODE [1,5]

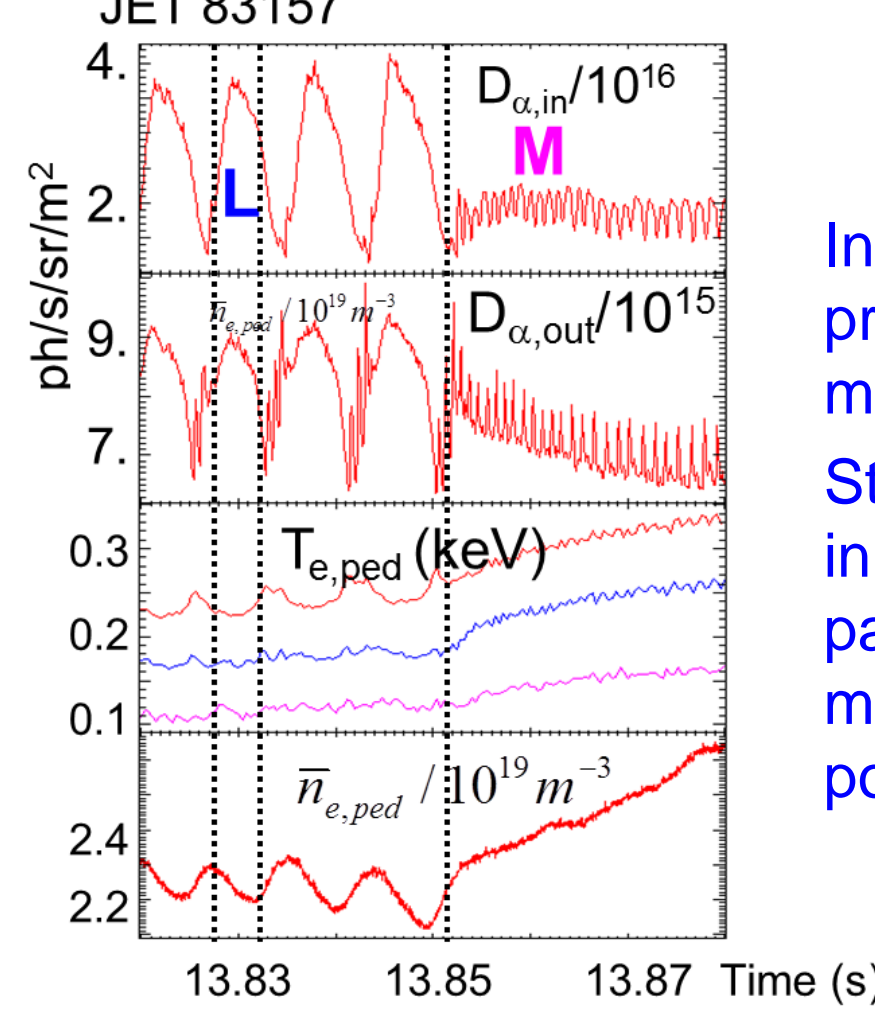
- In all slow L to H transitions in the JET ILW we have observed a weak H-Mode: the density pedestal steepens notably, density increases and a weak electron temperature pedestal forms.
- The M-phase has a coherent magnetic oscillation ($n=0$, $m=1$, up-down), typically without ELMs. Can be stationary for >10s if heating and density are kept near the $P_{th,L-H}$. It is called **M**-mode because of its **m**agnetic features and **m**edium confinement.
- Observed with ICRH, NBI heating and Ohmic plasmas. Seen in both ITER-Like Wall (Be wall, W divertor) & all Carbon PFCs. Mode already present in JET DT plasmas (1998).
- $P_{th,L-H}$ transition is typically measured with a slow power ramp: in most cases at JET these are L-M transitions.
- Similar oscillations described in other devices: ASDEX [3,6], EAST [4].
- The M-mode has a clear $n=0$, $m=1$ coherent magnetic oscillation (up-down), Mirnov measurements at plasma top are correlated with pedestal and SOL fluctuations, such as:
 - Inner and outer divertor D_{α} , out of phase.
 - divertor Langmuir probes and fast infra-red on outer strike.
 - density pedestal: reflectometer, interferometer, and Li beam BES
 - temperature pedestal ECE channels

SEQUENCE OF EVENTS: varied phenomenology.



High density branch:

- dithering transitions [2], then clean M-mode.
- M-mode seen during H phases
- As power increases, type I ELMs can be mixed with M-mode, eventually transition to ELM free, followed by type I ELMy.

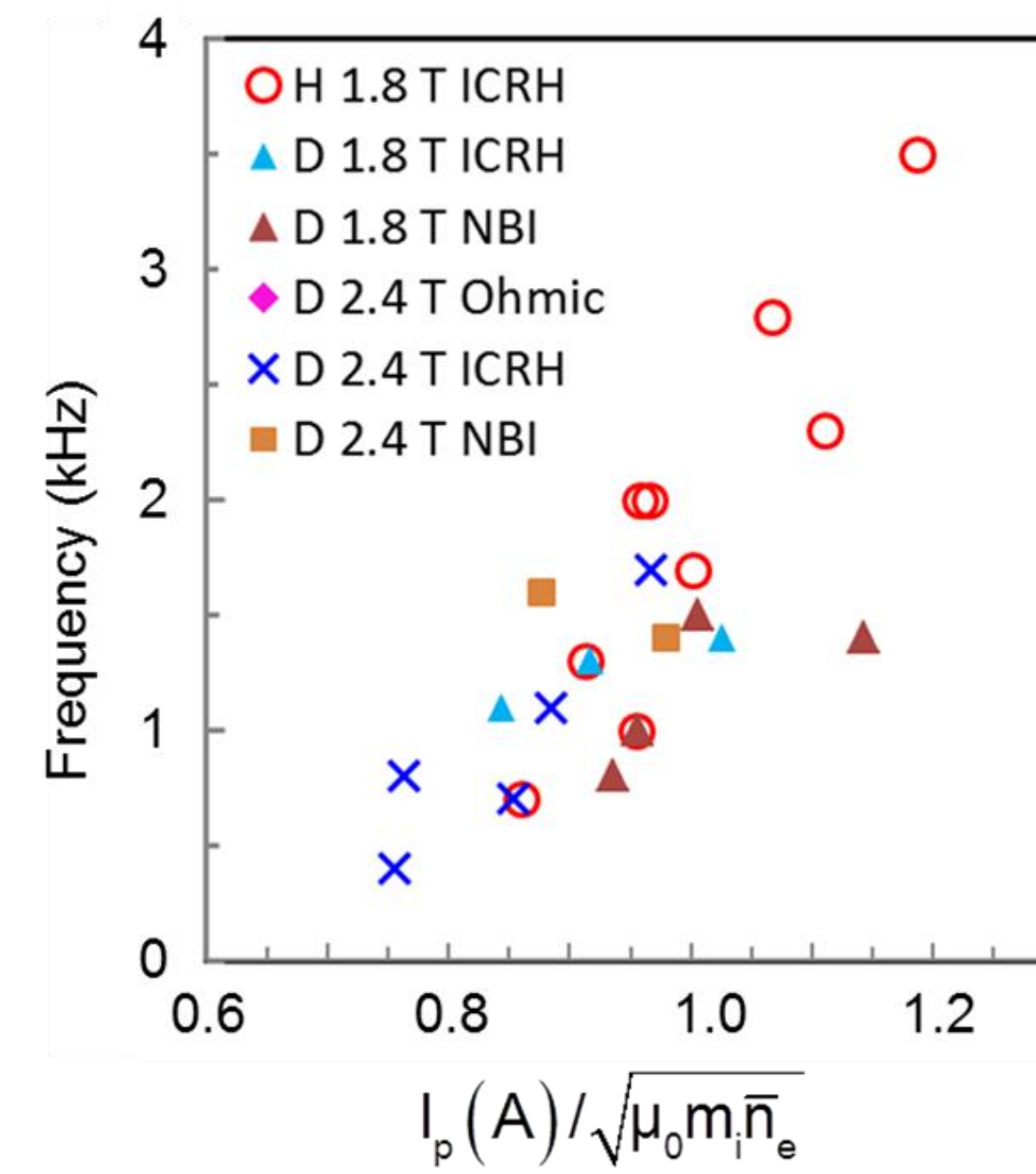


Inner detachment precedes transition to M-mode.
Strong in/out asymmetry in divertor recycling pattern is beneficial for H-mode access at reduced power [2]

Low density branch:

- L-mode, transition to M-mode (without dithering), then M-mode mixed with type III ELMs (incoherent $n=0$), followed by ELM-free and type I ELMy.

SCALING OF M-MODE FREQUENCY IN STEADY PHASES

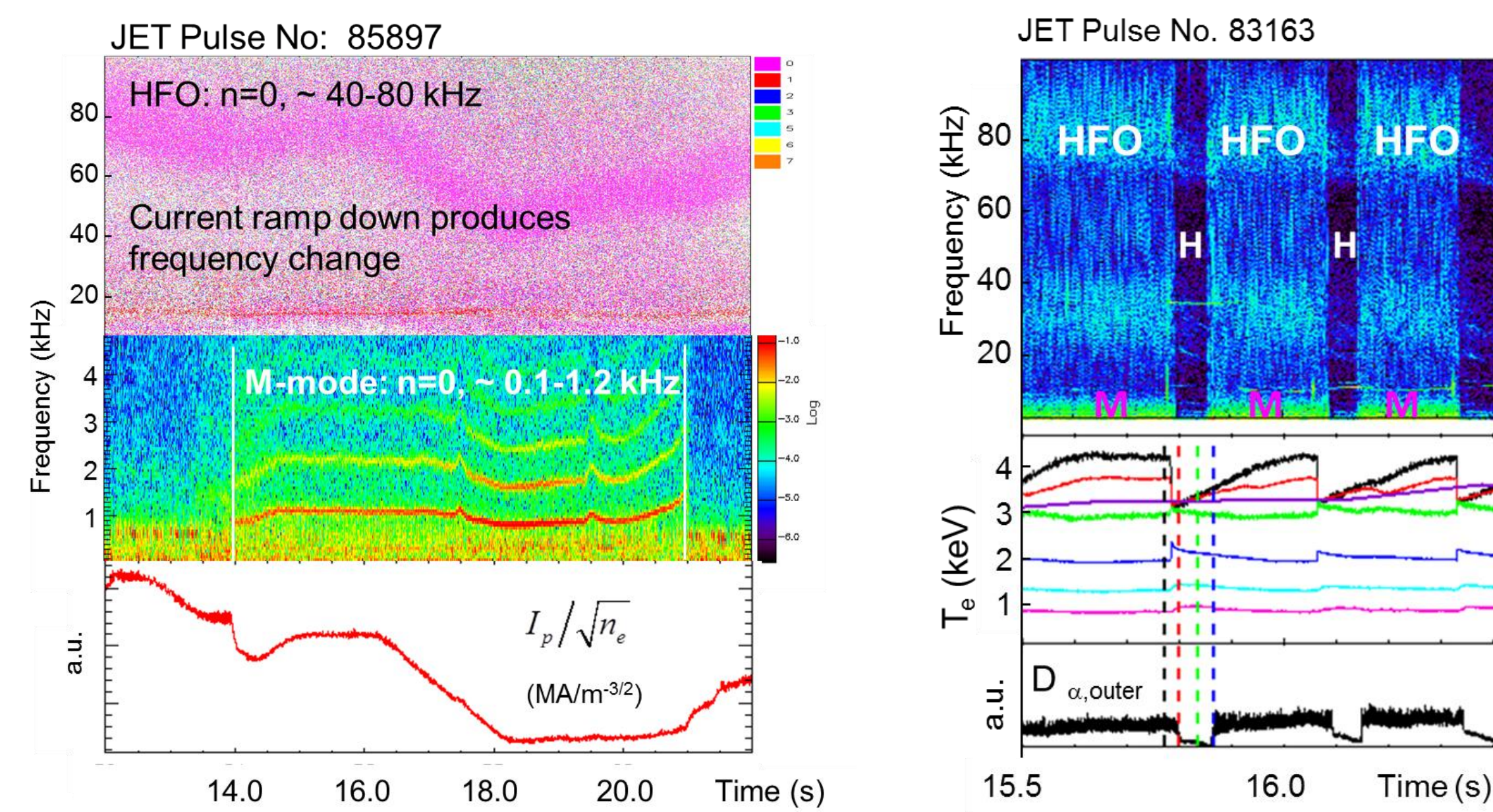


- Best ordering of data in M-mode phases with steady frequencies is achieved with poloidal Alfvén velocity,

$$V_{Alfvén,\theta} = B_0 / \sqrt{\mu_0 m_i n_i}$$

- B_0 dependency expected in axisymmetric modes ($k_z=0$)
- During transients such as current ramps and fuelling ramps we can observe some departures from the general trend seen in steady phases.
- M-Mode frequency does not scale with sound speed or $T_{e,ped}$. It is not a GAM
- In NBI plasmas density rises and mode frequency drops, although pedestal rotation rises.
- At high densities mode slows down to the point of disappearing in magnetic signals. In those cases it is difficult to disentangle natural mode frequency and vertical position control.

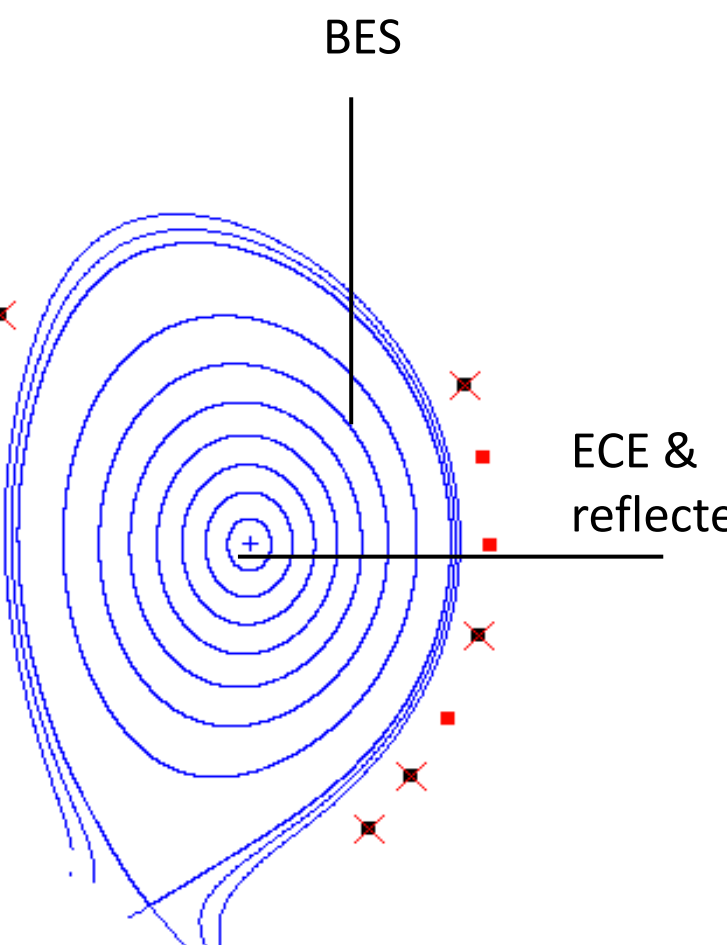
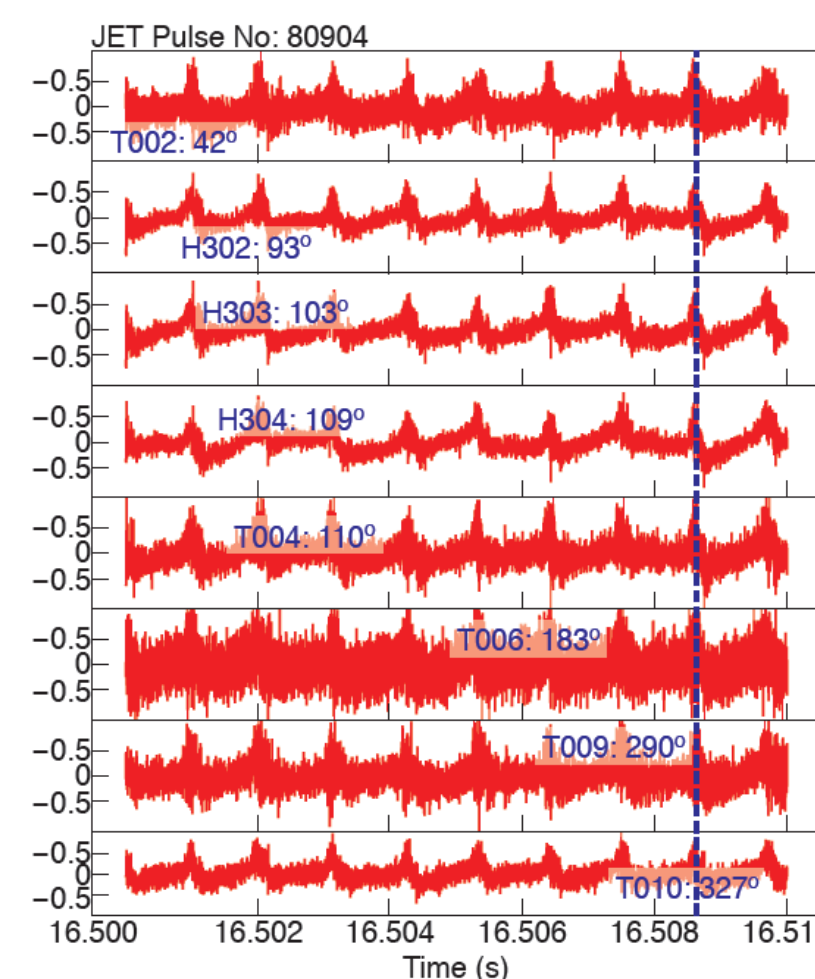
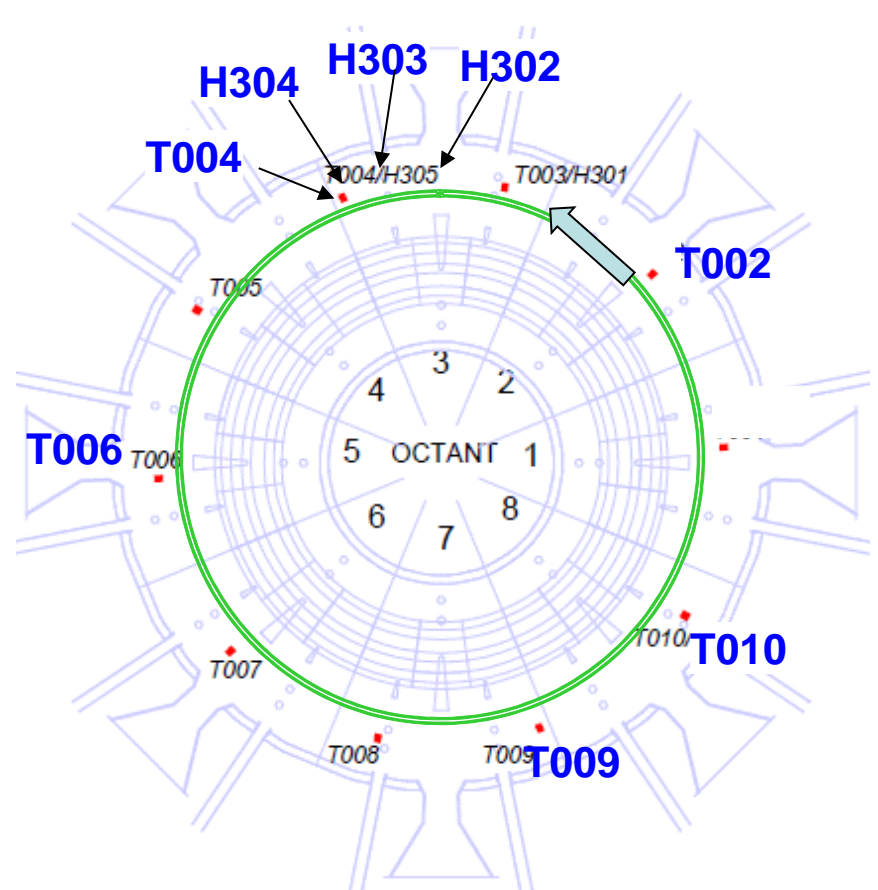
HIGH FREQUENCY OSCILLATION (HFO) [5, 7]:



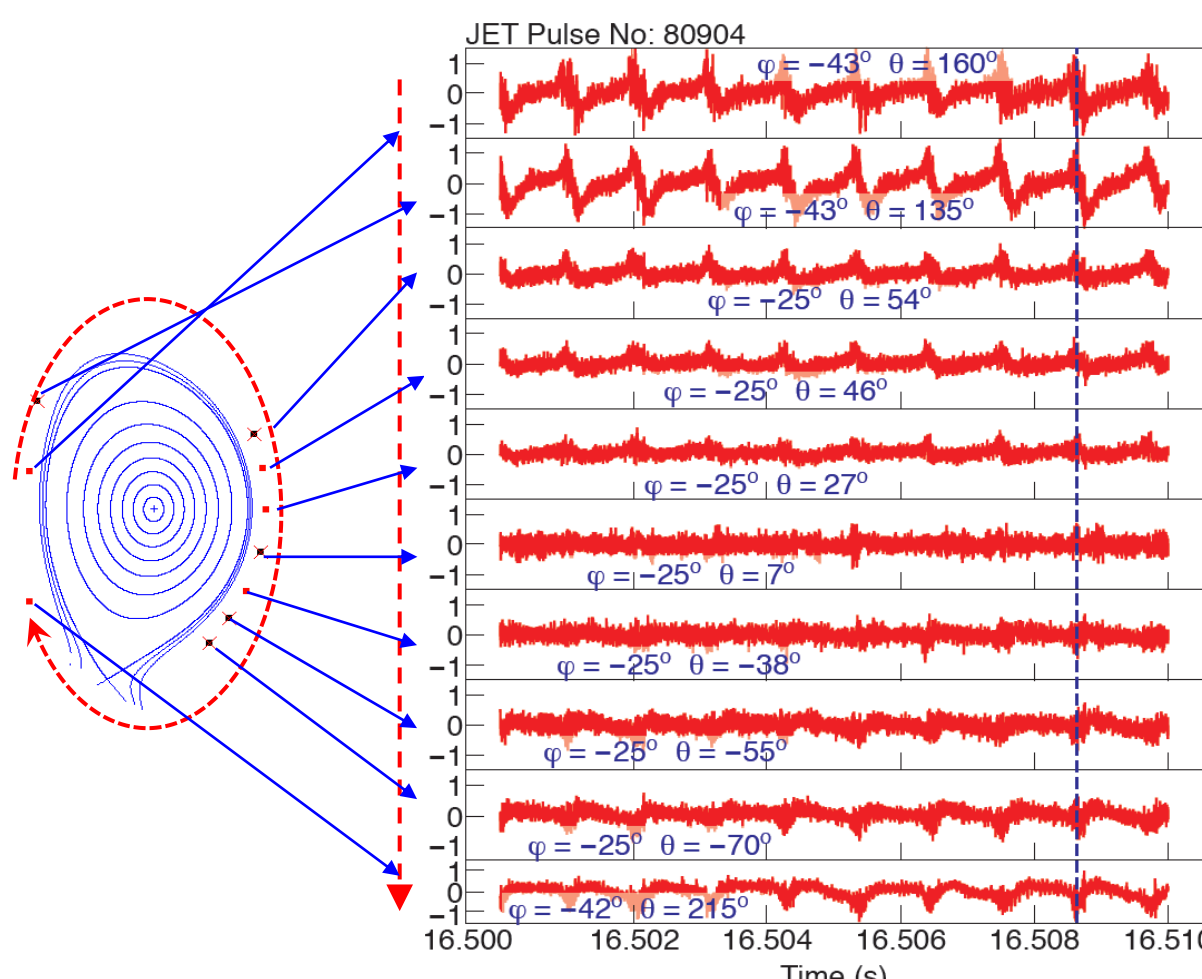
- HFO is a broadband $n=0$, $m=1$ up-down magnetic oscillation., both in L and M phases.
- HFO pulsates at M-mode frequency during M-mode.
- HFO disappears at transition to ELM-free and/or ELMy H-mode, can return during post-ELM periods of long compound ELMs.
- HFO has similar frequency scaling to M-mode, but at higher values.

MAGNETIC MODE GEOMETRY: ~UP-DOWN OSCILLATION

Toroidal array: $n=0$

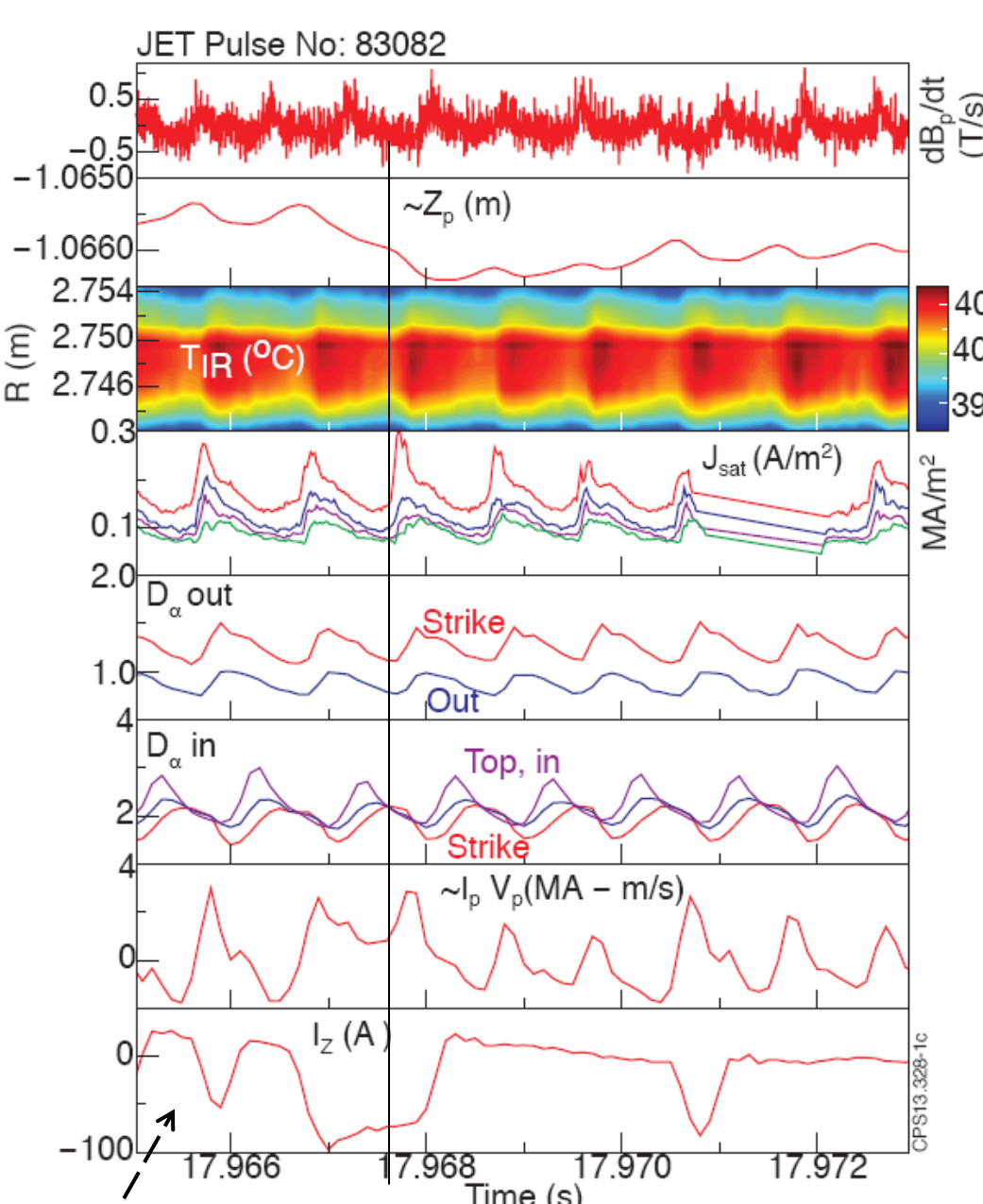


Poloidal array: $m=1$



- M-mode oscillation appears to be a <1 mm up-down motion of plasma current centroid. It is not an up-down motion of the whole plasma, but an oscillation of the current centroid of the pedestal flux surfaces.
- It is detected by the vertical position control system, which can respond to M-mode.
- But M-mode is not driven by control system. Vertical position control is adaptive, settles at 300 Hz, usually does not exceed 1 KHz, often misses.

OSCILLATIONS IN pedestal and SOL:



- The M-mode could be considered as a periodic series of L-H-L transitions in phase with the magnetic oscillations, similar to "dithering transitions" reported in AUG [3,6] or Limit Cycle Oscillations reported in EAST[4].
- When the plasma is "up" there is an increase in temperature (IR), Ion Saturation Current & Da light in outer strike area: a release of particles and energy
- From Langmuir Probe measurements there is no apparent motion of the outer strike. The magnetic oscillation does not affect the separatrix position.
- Note that the D_{α} light is out of phase in inner and outer strikes. This is a reflection of partial detachment in the inner leg, which appears to be beneficial to the L-M transition [2].

- Comparison of correlation reflectometry and fast ECE data (both equatorial measurements) show that oscillations in n_e and T_e at the top of the pedestal are in phase, indicating a p_e or ∇p_e oscillation Further analysis is required.
- Fast Li beam measurements show that M-mode is observed in the density profile at the top of the plasma. It is an oscillation in density pedestal width, rather than an up-down global displacement.
- The data so far indicates that the M-mode is a combination of an up-down oscillation of flux surfaces in the pedestal gradient region, punctuated by periodic expulsions of particles and energy from the pedestal top, which occur as the plasma current centroid moves upwards (or the toroidal current near the X-point erodes?).

OUTLOOK:

- Availability of fast Li beam profiles and fast IR, together with improved fast ECE and Doppler reflectometry should provide better analysis capabilities in future experiments.
- There is no available theory for either M-mode or HFO. A challenge to the community?
- Must clarify naming convention, distinguish dithering, M-mode, type III ELMs, etc.

- [1] E. R. Solano et al., 40th EPS Conference on Plasma Physics (2013), P4.111 *M-mode in JET*
- [2] E. Delabie et al., in Proceedings of the 24th IAEA FEC (2014), EX/P5-24. *Dithering transitions in JET*
- [3] H Zohm et al 1995 Plasma Phys. Control. Fusion 37 437 *like M-mode, called dithering transitions*
- [4] H. Q. Wang et al., Nucl. Fusion **52** (2012) 123011 *LCO in EAST*
- [5] N. Vianello et al., 42nd EPS Conference on Plasma Physics (2015), P2.133 *M-mode & HFO in JET*
- [6] G. Birkenmeier et al., ibid P1.1253 *like M-mode, described as I-phase in AUG*
- [7] K. H. Burrell et al, Phys. Fluids B 2, 1990. *HFO in DIII-D*